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Estimation of cosmic rays on the spectrometer sensors

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The SNAP spectrograph has very low noise requirements for the detector system, particularly for the IR (electronics included). Studies are needed to ensure the required performance and to evaluate the contamination of the signal as a result of radiation-induced –transients coming from ionizing particles.

Radiation environment

For SNAP, we consider a very high earth orbit (10000, 150000 km). This is outside the radiation belts most of the time and we assume the detector is turned off when the satellite goes through this zone. We also assume the detector to be subject to a very small geomagnetic cutoff. At these altitudes, the primary spectrum is composed of:

- ✓ **Galactic cosmic rays:**

The primary flux mainly includes contributions from protons (85%) and He (13%). Energy range of the cosmic rays is from the MeV range to several TeV. The shielding of instruments is essential, and the exact shielding geometry needs to be simulated and optimized. NGST studies [1] assume a shielding of 100 mils Al, corresponding to an ~ 100 MeV cut off. The flux can be considered to be isotropic.

- ✓ **Solar wind**

The solar wind is composed of an isotropic cloud of very low energy protons, ions and electrons (few eV), equivalent to neutral plasma. It has almost no effect and will not be considered.

- ✓ **Solar particle events**

The SNAP mission will occur during a period of maximum solar activity (between 2010 and 2014). The contribution to the mainly proton flux from solar flares, which occur several times per day over a period of several hours, is estimated in NGST studies to be ~ 0.4 p/cm^2/s at the NGST orbit (> ~100 MeV). Coronal arcs, which occur typically 10 times per year over a period of several days, are a more severe problem, as fluxes of 2000 p/cm^2/s are typical. This needs a careful evaluation for SNAP: measurements analyzed by NGST from the GOES satellite in the sun spot cycle 1986-1996 suggest that a 5% downtime could be expected for solar fluxes (E > 50 MeV) exceeding 25 p/cm^2/s and that fluxes of >5 p/cm^2/s in addition to the galactic flux were frequent.

Secondary particles are produced by primary particles through the spacecraft shielding and may contribute to the ionization environment. We can think to electrons produced in the sensitive volume of the focal plane, neutrons causing activation on spacecraft materials, δ-rays, bremstrahlung etc. This needs to be modeled with Geant.

Rate estimation

We have made a crude estimate with a parameterization for E> 0.1 GeV/n from Papini et al [2] which considers the dependence on solar cycle (primarily for E < 1 GeV). The calculation is made for maximum and minimum solar cyle and gives 7 p/cm^2/s at maximum and 2 p/cm^2/s at minimum, an average of 4.5 p/cm^2/s. This evaluation does not include coronas; during corona eruptions (typically 1 per month) you give up beyond a certain threshold.

Calculations that have been performed by SNAP using the Cream96 tool included shielding [3] give 4 p/cm^2/s. NGST have a very similar environment at the high altitude L2 Lagrange point and they have estimated the rate at 5 p/cm^2/s, with shielding. In addition, NGST assumed for instrumental considerations, solar contributions of 5 p/cm^2/s during periods of solar activity.

These galactic rates are in good agreement and can be compared to current measured values.

HST WFPC-2 (Instrument Handbook)	1.8 /chip/s
XMM (preprint,Ferrando et al.)	2.2/cm^2/s
Goddard, J.Shali	4/ cm^2/s
NGST	5/cm^2/s
SNAP	4/cm^2/s
Our estimation Max	7/cm^2/s
Min	2/cm^2/s
Likely	4.5/cm^2/s

Detector Evaluation

The spectrometer will be equipped with two sensors: a CDD Berkeley type of 15 $\times$15μm^2 pixel size and 300 μm thickness, and a HgCdTe 1024x1024 pixel array of 18x18 μm^2 pixel size. The thickness of this detector is not yet defined and is assumed to be between 10 to 30 μm.

Detector occupancy

CCD

A cosmic traversal of the 300 μm thick CCD detector will on average be characterized by a line of ~20 pixels (geometric), with additional adjacent hits from diffusion. For a diffusion of 5 μm, at least 20 % has to be added, leading to average of 25 pixels/hit.

HgCdTe

From the HgCdTe geometry we derive a first estimate of the number of pixels affected by the hit. For an isotropic cosmic ray distribution, there is a geometric average of between 1.8 and 3.3 HgCdTe pixels hit depending on the thickness. For a charge diffusion of around 3% in adjacent pixels (a few μm) and cross talk arguments [6] then an average of ~5 pixels are affected in a 10 μm thickness HgCdTe sensor. The cosmic hit in the pixel detector will typically be star-shaped.

We can compare these estimates with the number of pixels estimated from existing data.

- In the HST, the WFPC2 [4] used a CCD of 15x15 μm^2 pixel size and 10-µm thickness. They measure an average of 4 hit pixels per traversed particle. These data are under-sampled like the SNAP spectrograph, and it is noted that in these configurations, it is more difficult to separate low energy cosmic rays.
- In XMM, EEV type 22 CCDs [5] are used. Each CCD is an array of 600x600 pixels, with 40x40 μm^2 pixel size, an epitaxial layer of about 80 µm and a depletion thickness of 35 µm. They mention a mean of 39 pixels /hit . This larger multiplicity (a crude expectation is near 20) is caused by a non depleted Si layer with low field and a large diffusion below the sensitive area.

This shows that a careful detector design is needed, particularly for large thickness.

Exposure time requirement

The actual strategy is to have many short exposure times. The requirement is to stay below 10 % of hit pixels in one exposure time

1. For the CCD, a nominal exposure time less than 300 seconds is required. A factor 1.5 on the occupancy can be added on the expected value [5], [6] .The main point to be explored is the actual thickness which allows having an extended red response. The CCD will be delivered by the Berkeley team and enter in the general development plan of new type of optical CCD. This CCD will have also an enhanced radiation tolerance. Specification will be updated if necessary after simulation studies (trade off between the pixels size and thickness in one side and the QE and optical design in the other side)
2. The nominal exposure times on the IR sensor are of 1000 seconds. Since the main concern is to operate at a very low background level, an optimization is needed to be able to relax this exposure if possible. With the SNAP estimate rate, we need a thickness of 10-20 µm. In comparison HST, with a rate two times lower, find 3.8 % of hit pixels in 2000 seconds.

Further studies

Algorithms to reject cosmics are being developed assuming an up-the-ramp sampling for data acquisition and/or interpolation between pixels. This point has to be evaluated and demonstrated. The well capacity has to ensure no saturation.

The tolerance of the detector array and readout to total ionization dose needs to be known for very low background usage. For the sensors, further studies are needed in next phases of the project to take care of displacement damage that can increase the mean dark current (referred as ‘hot pixel’), or to evaluate global offsets induced by low dose rate (the total doses are nevertheless relatively small). As previously noted, a trade off with the shielding thickness may be necessary in this context.

Not included in the above discussion, but also of importance to study, is the possibility of single-event latch-ups, etc. in the pixel or system readout electronics (ROIC) due to the passage of individual cosmics.

The operating temperature will be a concern in this study. The actual baseline is to stay at 140 ^{o}K at the global focal plane but we not exclude the possibility to go down to 70 ^{o}K if needed. The wavelength cut-off value is also another open parameter in this evaluation.

Conclusion

The cosmic rate expected during SNAP operation, will have an impact on the detector design and its geometry. Requiring less than 10 % of hit pixels will drive the exposure times. Factors 2 on expected rate and on detector occupancy are still possible and will be carefully evaluated.

A large effort will be made on these issues with the NGST - selected detector [6]. As long as we follow the same requirements, the detector will be evaluated in radiation at an operating temperature < 70 ^{o}K. If we plan our own development or make a different set of requirements, in particular for the electronics, some caution has to be taken.

Further work will include:

- ✓ Understanding the shielding
- ✓ Clarify the IR sensor specification and geometry
- ✓ Care on the detector design to take in account previous points
- ✓ Modeling radiation effects

References:

[1] The radiation environment for the NGST L.Barth, September 2000
Simulations of Radiations effects on NGST, B.Fodness, Feb. 2002

[2] Papini et al, Nuevo Cimento C19, 367(1996)

[3] Cream96 http://crsp3.nrl.navy.mil/creme96/

[4] WFPC2 – Instrument Handbook –

[5] Cosmic-rays identification and rejection in the EPIC-MOS cameras onboard XMM-Newton, P.Ferrando et al.

[6] Effect of cosmic rays on NIR exposure times B.J Rausher, may 2000